WAD 2917
Eff# 8a
2/24/93

BURLINGTON
ENVIRONMENTAL

TOTAL PERMIT
ADMINISTRATIVE RECORD
TOTAL NUMBER OF PAGES

RECEIVED
FEB 25 1993
RCRA PERMITS SECTION

FILE COPY

February 24, 1993

CERTIFIED MAIL

Mr. David Croxton
EPA Project Coordinator
U.S. EPA
1200 Sixth Avenue, M/S HW-106
Seattle, WA 98101

Re: Burlington Environmental Inc. (BE) Pier 91 RFI Workplan

Enclosed are the final Tidal Monitoring Workplan and Pumping Test Workplan for the Pier 91 Facility. The draft workplans were submitted in October 1992 as required by the USEPA July 1992 conditional comments/approval of the Pier 91 RFI Workplan. These final workplans address USEPA's February 4, 1993 comments, and a response summary is included.

If you have any questions or require further information, please contact me at (206) 654-8153.

Sincerely,

John Stiller
Project Coordinator

cc: Galen Tritt - Ecology NWRO

RESPONSES TO U.S. EPA COMMENTS ON BURLINGTON ENVIRONMENTAL'S OCTOBER 1992 DRAFT PUMPING TEST AND TIDAL MONITORING WORK PLANS

TIDAL EFFECTS

1) Three or four additional lower aquifer wells will be monitored instead of monitoring 3 wells in the upper aquifer. This modification was made since data previously collected indicates that little if any tidal effect on the upper aquifer is expected due to its large storage capacity and because monitoring additional wells in the lower aquifer will provide more critical data to understanding the tidal impacts on ground water flow beneath the BEI facility.

For similar reasons stated above for not monitoring the upper aquifer, monitoring the water level of Lake Jacobs is also unnecessary. Although it was not specifically discussed during the meeting, EPA recommends that the final deep monitoring well at Pier 91 be included in the tidal monitoring study as a substitute for not having to install a stilling well and monitor Lake Jacobs. In EPA's estimation, adding the seventh deep well to the tidal monitoring study will provide additional worthwhile data for determining tidal impacts.

Response to Comment (1):

Water levels will be measured in deep-aquifer monitoring wells only. See Section 3.2, Groundwater Levels, in the revised Tidal Monitoring Work Plan.

2) The workplan will be modified to adjust the water level monitoring interval to 30 minutes instead of hourly. Thirty minute intervals are more consistent with other studies in the available literature.

Response to Comment (2):

Water levels will be measured once every 30 minutes. See Section 3.2, Groundwater Levels, in the revised Tidal Monitoring Work Plan.

3) The need for monitoring well 107B will be re-examined after completion of the 1st tidal monitoring test when better data regarding groundwater flow direction in the lower aquifer will be available. This discussion is particularly relevant since it pertains to earlier written communications between BEI and EPA regarding RFI modification plans requested by BEI to substitute well 107B for well 122B (see July 30, 1992 letter from BEI and EPA's response dated September 30, 1992).

Response to Comment (3):

Burlington will evaluate the need for an additional deep-aquifer monitoring well following the first tidal monitoring period. See Section 3.2, Groundwater Levels, in the revised Tidal Monitoring Work Plan.

4) EPA raised the issue of monitoring for 2 periods in each month instead of one in order to capture the tidal influence without the need for the additional tests. EPA agreed to allow BEI to demonstrate the adequacy of their proposal before requiring any additional monitoring. EPA does recommend that BEI choose to monitor the tidal effects at a time in the month when a high fluctuation in the tide is expected in order to get good data resolution.

Response to Comment (4):

Within any given month, the tide level extremes tend to occur consecutively within the same 12.25-hour period. That is, the highest level tends to follow the lowest level, or vice versa, with a time difference of approximately six to seven hours. Although this relationship is approximate, the predicted tide levels for Elliott Bay during the months of February, March, and August 1993 (See attached figures) suggest that it is fairly accurate. This tendency makes it possible to observe the groundwater system's response to monthly tide level extremes by conducting a single 75-hour tidal monitoring session.

Burlington concurs with the USEPA on the benefit of conducting the tidal monitoring session during a period of maximum tidal variation within the scheduled months. Provided that the system is linear and the time lag is not too great, this approach is expected to maximize the magnitude of the groundwater system's response, thereby increasing the likelihood that the response will be measurable.

PUMPING TEST

1) Burlington Environmental will collect tidal and barometric data in order to make corrections to the pump test for barometric efficiency and tidal influence.

Response to Comment (1):

Burlington has agreed to collect these data. See Section 4.2.1, Corrections for Barometric and Tidal Effects, in the revised Pumping Test Work Plan.

2) Burlington Environmental will submit plans for a step drawdown test (which will assist in determining pumping rate and duration) and for monitoring of groundwater conditions prior to the actual pump test. The period of monitoring antecedent conditions must be performed on a stabilized system (i.e., monitoring the deep aquifer for a set period of time after it has stabilized from the step drawdown test).

Response to Comment (2):

Burlington has included plans for a step-drawdown test in Section 2.1, General Procedures, in the revised Pumping Test Work Plan.

3) Although it is not a necessary aspect of the pump test, BEI agreed to give consideration to a time series analysis of water quality during the pump test since the pump test represents a first opportunity to gather water quality data from currently unmonitored areas. This monitoring could be done in a number of ways, including some combination of screening (e.g., HNU) and sampling.

Response to Comment (3):

Burlington has considered periodic water quality sampling during the pumping test, as suggested by the USEPA. Burlington has concluded that such testing should not be conducted as part of the planned pumping test, for the following reasons. First, such testing is not consistent with the overall objective of the pumping test, which is to infer the degree of hydraulic connection across the silty sand layer, between the shallow and deep aquifers. Second, it is questionable whether the results of such testing would yield useful information. Groundwater pumped out of a well during such a test would originate from distant points in the aquifer, and would undergo extensive mixing as it flowed toward and into the pumping well. As a result, it would be impossible to infer the point of origination and the initial concentration of the sampled groundwater. Burlington believes that more useful information on groundwater quality would be derived from the groundwater sampling proposed in the RFI Work Plan.

4) The possibility of performing a second pump test in another season was briefly discussed. It was agreed that determining the need for a second pump test at this time was premature and further discussion of this issue would await final results of this pump test.

Response to Comment (4):

Decisions regarding further hydraulic testing of the deep aquifer will be based, in part, on the results of this initial pumping test. Because the initial deep aquifer pumping test has not yet been conducted, discussion of further testing is premature.

FEBRUARY 1993

Feet scale: 12, 6, 0 — hours: 6 AM, 12, 6 PM

Date	Day	Tide 1	Tide 2	Tide 3	Tide 4	Notes
1	Monday	1:16 / 9.1	5:18 / 7.8	10:39 / 10.5	6:29 / 0.7	Sunrise 7:39, Sunset 5:08
2	Tuesday	2:35 / 9.9	6:43 / 8.3	11:34 / 10.5	7:24 / -0.1	
3	Wednesday	3:21 / 10.7	7:56 / 8.2	12:33 / 10.5	8:14 / -0.8	
4	Thursday	3:56 / 11.4	8:54 / 7.7	1:36 / 10.7	8:59 / -1.4	
5	Friday	4:29 / 12.0	9:43 / 6.9	2:35 / 11.0	9:44 / -1.6	
6	Saturday	4:57 / 12.5	10:28 / 5.9	3:34 / 11.2	10:29 / -1.5	Full Moon
7	Sunday	5:27 / 12.8	11:12 / 4.8	4:33 / 11.2	11:12 / -1.0	
8	Monday	5:58 / 13.0	11:56 / 3.5	5:33 / 11.1	11:54 / 0.0	
9	Tuesday	6:30 / 13.1	12:44 / 2.4	6:33 / 10.8		
10	Wednesday	12:39 / 1.3	7:05 / 13.0	1:33 / 1.5	7:39 / 10.4	
11	Thursday	1:26 / 2.8	7:44 / 12.7	2:25 / 0.9	8:51 / 9.9	
12	Friday	2:14 / 4.4	8:23 / 12.3	3:24 / 0.6	10:14 / 9.5	Lincoln's Birthday
13	Saturday	3:09 / 5.8	9:09 / 11.7	4:27 / 0.5	11:50 / 9.5	Last Quarter
14	Sunday	4:19 / 7.0	10:00 / 11.0	5:36 / 0.4		St. Valentines Day
15	Monday	1:19 / 10.0	5:52 / 7.6	11:06 / 10.4	6:43 / 0.3	Sunrise 7:19, Sunset 5:31
16	Tuesday	2:29 / 10.6	7:29 / 7.6	12:15 / 10.0	7:45 / 0.1	
17	Wednesday	3:21 / 11.1	8:39 / 7.1	1:24 / 9.8	8:36 / 0.1	
18	Thursday	4:03 / 11.4	9:30 / 6.5	2:23 / 9.8	9:19 / 0.2	
19	Friday	4:37 / 11.6	10:06 / 5.9	3:15 / 9.9	9:55 / 0.4	
20	Saturday	5:05 / 11.6	10:41 / 5.3	3:57 / 9.9	10:30 / 0.7	
21	Sunday	5:25 / 11.6	11:10 / 4.6	4:39 / 10.0	11:03 / 1.2	New Moon
22	Monday	5:45 / 11.6	11:39 / 3.9	5:21 / 10.0	11:34 / 1.7	Washington's Birthday
23	Tuesday	6:04 / 11.5	12:11 / 3.2	6:03 / 10.0		
24	Wednesday	12:06 / 2.5	6:25 / 11.4	12:46 / 2.5	6:48 / 9.9	
25	Thursday	12:41 / 3.3	6:48 / 11.3	1:21 / 2.0	7:36 / 9.7	
26	Friday	1:16 / 4.3	7:15 / 11.1	2:03 / 1.7	8:35 / 9.4	
27	Saturday	1:58 / 5.3	7:47 / 10.8	2:49 / 1.4	9:38 / 9.2	
28	Sunday	2:45 / 6.3	8:19 / 10.5	3:40 / 1.2	10:54 / 9.2	Sunrise 6:58, Sunset 5:52

JANUARY

S	M	T	W	T	F	S
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

MARCH

S	M	T	W	T	F	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

Tidelines ™

MARCH 1993

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
6 AM 12 6 PM	6 AM 12 6 PM	6 AM 12 6 PM	6 AM 12 6 PM	6 AM 12 6 PM	6 AM 12 6 PM	6 AM 12 6 PM
	1 Sunrise 6:51 Sunset 5:54 *First Quarter* 3:44 9:04 4:39 7.2 10.2 0.9	**2** 12:23 4:59 9:57 5:40 9.5 7.7 9.9 0.6	**3** 1:36 6:26 11:06 6:44 10.1 7.8 9.7 0.2	**4** 2:25 7:36 12:21 7:41 10.7 7.2 9.8 -0.1	**5** 3:05 8:33 1:32 8:33 11.3 6.3 10.1 -0.3	**6** 3:37 9:20 2:41 9:23 11.7 5.0 10.6 -0.2
7 4:08 10:03 3:42 10:08 12.1 3.6 11.0 0.2	**8** *Full Moon* 4:40 10:48 4:41 10:54 12.4 2.2 11.3 1.0	**9** 5:12 11:30 5:39 11:39 12.5 1.0 11.4 2.0	**10** 5:45 12:15 6:38 12.5 0.1 11.3	**11** 12:24 6:23 1:01 7:40 3.1 12.3 -0.5 11.0	**12** 1:13 7:02 1:52 8:46 4.3 11.9 -0.5 10.6	**13** 2:03 7:44 2:48 10:02 5.5 11.3 -0.3 10.3
14 3:04 8:32 3:48 11:27 6.4 10.6 0.2 10.1	**15** Sunrise 6:23 Sunset 6:16 *Last Quarter* 4:22 9:32 4:57 7.0 9.8 0.7	**16** 12:44 5:58 10:47 6:07 10.3 7.1 9.2 1.0	**17** *St. Patricks Day* 1:48 7:27 12:08 7:13 10.6 6.6 8.9 1.2	**18** 2:38 8:27 1:26 8:08 10.8 5.9 8.9 1.4	**19** 3:19 9:06 2:28 8:52 11.0 5.1 9.1 1.7	**20** *Vernal Equinox* 3:46 9:41 3:18 9:32 11.0 4.3 9.4 2.0
21 4:10 10:09 4:04 10:04 10.9 3.5 9.8 2.4	**22** 4:30 10:38 4:43 10:36 10.9 2.7 10.0 2.9	**23** *New Moon* 4:48 11:06 5:22 11:11 10.8 1.9 10.3 3.4	**24** 5:07 11:35 6:01 11:47 10.8 1.3 10.4 4.0	**25** 5:32 12:10 6:43 10.8 0.7 10.5	**26** 12:22 5:57 12:44 7:31 4.7 10.7 0.3 10.4	**27** 1:01 6:26 1:23 8:24 5.4 10.5 0.1 10.3
28 1:44 6:57 2:06 9:19 6.1 10.2 0.1 10.2	**29** 2:35 7:36 2:58 10:25 6.7 9.9 0.2 10.2	**30** 3:38 8:26 3:54 11:31 7.1 9.5 0.4 10.3	**31** Sunrise 5:51 Sunset 6:39 *First Quarter* 4:56 9:34 4:57 7.1 9.1 0.6			

Feet: 12, 6, 0

FEBRUARY

S	M	T	W	T	F	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28						

APRIL

S	M	T	W	T	F	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	

TM

AUGUST 1993

Date	Day	Tide 1	Tide 2	Tide 3	Tide 4	Notes
1	SUNDAY	3:47 10.1	10:57 -1.3	6:20 11.6	11:40 6.0	Sunrise 5:45, Sunset 8:49
2	MONDAY	4:39 10.0	11:36 -1.0	6:48 11.6		Full Moon
3	TUESDAY	12:19 5.4	5:25 9.8	12:11 -0.5	7:17 11.6	
4	WEDNESDAY	12:55 4.8	6:10 9.6	12:43 0.1	7:40 11.5	
5	THURSDAY	1:30 4.2	6:57 9.4	1:18 1.0	8:02 11.3	
6	FRIDAY	2:09 3.6	7:45 9.1	1:53 1.9	8:29 11.1	
7	SATURDAY	2:47 3.1	8:39 8.8	2:32 3.0	8:55 10.8	
8	SUNDAY	3:29 2.6	9:38 8.5	3:11 4.1	9:27 10.6	
9	MONDAY	4:18 2.1	10:51 8.3	3:57 5.3	10:00 10.3	
10	TUESDAY	5:10 1.7	12:13 8.3	4:55 6.3	10:38 10.0	Last Quarter
11	WEDNESDAY	6:09 1.3	1:46 8.6	6:04 7.1	11:26 9.8	
12	THURSDAY	7:08 0.7	3:02 9.3	7:24 7.5		
13	FRIDAY	12:21 9.7	8:02 0.1	4:00 9.9	8:37 7.4	
14	SATURDAY	1:17 9.7	8:53 -0.5	4:33 10.5	9:33 7.0	
15	SUNDAY	2:19 9.9	9:41 -1.0	5:05 11.1	10:19 6.3	Sunrise 6:05, Sunset 8:22
16	MONDAY	3:18 10.2	10:25 -1.2	5:33 11.5	11:05 5.4	
17	TUESDAY	4:15 10.5	11:07 -1.2	6:02 11.8	11:47 4.2	New Moon
18	WEDNESDAY	5:11 10.7	11:49 -0.8	6:32 12.1		
19	THURSDAY	12:29 3.0	6:09 10.8	12:31 0.0	7:01 12.3	
20	FRIDAY	1:14 1.9	7:09 10.7	1:16 1.1	7:36 12.3	
21	SATURDAY	2:03 0.9	8:12 10.4	2:02 2.5	8:12 12.1	
22	SUNDAY	2:52 0.3	9:18 10.0	2:52 3.9	8:54 11.8	
23	MONDAY	3:48 -0.1	10:37 9.6	3:48 5.2	9:41 11.3	
24	TUESDAY	4:50 -0.2	12:03 9.5	4:55 6.3	10:31 10.7	First Quarter
25	WEDNESDAY	5:59 -0.2	1:33 9.7	6:18 6.9	11:36 10.2	
26	THURSDAY	7:08 -0.2	2:48 10.2	7:50 6.9		
27	FRIDAY	12:48 9.7	8:14 -0.2	3:46 10.6	9:05 6.5	
28	SATURDAY	2:01 9.6	9:09 -0.2	4:30 11.0	10:01 5.8	
29	SUNDAY	3:04 9.6	9:59 0.0	5:08 11.1	10:42 5.1	
30	MONDAY	3:59 9.7	10:38 0.3	5:38 11.2	11:18 4.5	
31	TUESDAY	4:46 9.7	11:14 0.7	6:03 11.1	11:53 3.8	Sunrise 6:25, Sunset 7:55

JULY

S	M	T	W	T	F	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24

SEPTEMBER

S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25

TIDAL MONITORING WORK PLAN
FOR RCRA FACILITY INVESTIGATION
BURLINGTON ENVIRONMENTAL INC.
PIER 91 FACILITY
SEATTLE, WASHINGTON

February 1993

Prepared for:

Burlington Environmental Inc.
Seattle, Washington 98134

Project 624878

Prepared by:

BURLINGTON ENVIRONMENTAL INC.
Technical Services Division
2203 Airport Way South, Suite 400
Seattle, Washington 98134-2027
(206) 223-0336

TABLE OF CONTENTS

LIST OF TABLES

1 TIDAL MONITORING PROGRAM SUMMARY

1.1 Background and Purpose

This work plan outlines the proposed tidal monitoring program to be conducted as part of the RCRA Facility Investigation (RFI) at the Burlington Environmental Inc. (Burlington) Pier 91 facility. An RFI Work Plan (Burlington, April 1992) for the Pier 91 facility was conditionally approved by the U.S. Environmental Protection Agency (USEPA) in July 1992 (USEPA, 1992). One of the conditions that the USEPA imposed as a requirement for final approval of the RFI Work Plan was that Burlington submit plans for measuring the effects of the tidal cycle on groundwater flow. To satisfy that requirement, and to provide a basis for conducting the tidal monitoring program, Burlington submitted a tidal monitoring work plan to the USEPA in October 1992 (Burlington, October 1992). After discussions with representatives of the USEPA in December 1992, the USEPA submitted written comments on the tidal monitoring work plan to Burlington (USEPA, 1993). Those comments have been addressed in this version of the tidal monitoring work plan. This tidal monitoring work plan, if approved, will become an addendum to the existing RFI Work Plan.

1.2 Objectives

The overall objective of the tidal monitoring program is, as stated in the RFI Work Plan approval letter (USEPA, 1992), "... to determine the impact of tidal cycles on the <u>net</u> direction of ground water flow ...". More specific objectives include the following:

- to measure the diurnal variations of groundwater levels within the deep aquifer;
- to understand the effects of tidal forcing on groundwater levels within the deep aquifer;

- to understand the effects of tidal forcing on the horizontal components of groundwater flow within the deep aquifer;
- to estimate the time-averaged horizontal components of groundwater flow within the deep aquifer; and
- to understand any seasonal or barometric variations in these tidal effects.

A secondary objective of the tidal monitoring is to help evaluate whether or not an additional monitoring well is necessary in the deep aquifer. Specifically, the tidal monitoring data will be utilized to determine the need for monitoring well CP-107B. This well was initially proposed to be installed near the southwest corner of the leased property (Burlington, April 1992).

1.3 Schedule

Tidal monitoring will be conducted during two tidal monitoring sessions. The first tidal monitoring session will occur in March 1993, and the second in August 1993. The rationale for multiple tidal monitoring sessions is given in Section 4.4, Seasonal Effects.

This schedule will allow Burlington to perform tidal monitoring after all drilling, well installation, and well development activities have been completed. These activities could potentially cause unknown temporary disturbances to the potentiometric surface of the aquifer. Such disturbances could complicate the interpretation of tidal response data. This schedule is also intended to permit Burlington to interpret the data obtained from the first tidal monitoring session after the proposed laboratory permeability tests and the slug tests (see Section 3.5) have been completed. Since groundwater flow is determined in part by the hydraulic properties of the subsurface, it is important for these data to be available at the time the tidal monitoring data are interpreted.

1.4 Scope

A detailed description of the scope of this program is given in the following sections. In summary, the scope consists of the following elements:

- data collection;
- data analysis and interpretation; and
- reporting.

The data collection phase involves the periodic acquisition of various types of data during two tidal monitoring sessions. Pertinent data include deep-aquifer groundwater levels, barometric pressures, and tide levels. The data analysis and interpretation phase involves the estimation of the time-averaged system behavior. This includes the calculation of numerical measures of the groundwater system's response to tidal forcing. The reporting phase involves report preparation, and submittal to the USEPA according to the timeframe given in Section 5.

2 PREVIOUS WORK

2.1 On-Site Tidal Monitoring

The most relevant work performed to date to infer the tidal response of the groundwater system is that of Sweet-Edwards/EMCON (SE/E) (SE/E, 1989). This is the only known tidal study ever completed for Burlington's Pier 91 facility. A brief summary of this work is given below.

On May 6, 1988, a water-level change of 1.6 feet was measured in the deep-aquifer monitoring well CP-103B; the corresponding tide-level change was reported to be 13 feet (SE/E, 1989). SE/E also noted that the water-level fluctuation lagged the tide-level fluctuation by about 29 minutes.

On February 21-22, 1989, water levels in wells CP-108A and CP-108B were measured over a 24-hour period (from 15:22 on February 21, 1989, to 15:27 on February 22, 1989) using pressure transducers and an electronic data logger. Water levels were measured in wells CP-104B, CP-107, CP-109, and CP-110 during the last six hours of this same time period using an electronic water-level indicator. The tide level reportedly changed by approximately 13 feet during this period (SE/E, 1989). The measured water-level fluctuation in well CP-108B, which lies approximately 360 feet from Elliott Bay, was reported to have an amplitude of approximately 3.6 feet and to lag the tide-level fluctuation by approximately 40 minutes. No significant influence was reported for deep-aquifer well CP-104B, which lies approximately 730 feet from Elliott Bay. Similarly, no significant influence was reported in shallow-aquifer monitoring wells CP-107, CP-108A, CP-109, and CP-110. Based on these results, SE/E concluded that tidal influence in the deep aquifer is not expected to be significant at a distance greater than 400 feet from the shore (SE/E, 1989).

2.2 Other Tidal Monitoring

In addition to the work by Sweet-Edwards/EMCON discussed above, Converse GES performed tidal monitoring in the vicinity of the Pier 91 facility while completing studies for Pacific Northern Oil (Converse GES; 1989, 1990a, 1990b). Converse GES measured water levels in three monitoring wells located west of Lake Jacobs, over a period of approximately 27 hours during November 1989. Two of the wells are approximately 15 feet west of Lake Jacobs; the other well was approximately 50 feet west of Lake Jacobs. This area is approximately 200 feet southwest of the property that Burlington leases from the Port of Seattle, and lies between the Pier 91 facility and the shore of Elliott Bay, which lies approximately 240 feet west of Lake Jacobs. Water levels were measured using pressure transducers and an electronic data logger (Converse GES, 1990a). According to the boring logs included in Appendix A of the January 1990 report (Converse GES, 1990a), all three of the wells were completed at depths less than 20 feet below ground surface. These completion depths are comparable to those of wells installed in the shallow aquifer beneath the Burlington Pier 91 facility. However, it is not known whether the unit in which these wells are completed has been correlated stratigraphically with the shallow aquifer beneath the Burlington Pier 91 facility.

Three high tides and two low tides reportedly occurred during the tidal monitoring period. Graphs of water level versus time for some of the wells are presented in the reports. Total net fluctuations of water levels in the three wells varied from approximately 0.23 foot to 0.34 foot. Water-level fluctuations in all three wells were reported to be in phase with the tidal variations. The hydraulic gradient was inferred from water-level measurements, and was observed to change direction approximately 25 degrees over the monitoring period. The direction was toward the southeast or south-southeast. Converse GES (1990b) also obtained water-level measurements via a stilling well in Lake Jacobs over a 24-hour period during the tidal monitoring period. The total fluctuation in water level was approximately 0.05 foot.

Pacific Groundwater Group and Converse Consultants Northwest (PGG/CCN) present time plots of water-level measurements made during July 28 and 29, 1988, in five piezometers located in the short fill (PGG/CCN, 1990). The short fill is the area bounded to the north by Lake Jacobs and to the south by Smith Cove of Elliott Bay. These results were reportedly used for calibration of a hydraulic/transport model. The piezometers were completed in artificially-emplaced fill materials.

The relationship between the response of water levels in the short fill and in the fill materials west of Lake Jacobs, and that of water levels in the units underlying the property leased by Burlington, if any, is not well known. Because the shallow subsurface conditions in the areas south and west of Lake Jacobs may differ from those of the leased property, and the groundwater flow is two- or three-dimensional, a simple relationship between the responses in the two areas is not likely to be found.

3 DATA COLLECTION

Sections 3.1 through 3.4 describe data to be collected during each tidal monitoring session. Section 3.5 describes related data to be collected as part of other RFI activities.

3.1 Tide Level

The National Ocean Service (NOS) continuously measures tide levels at the Colman Docks area of Elliott Bay. The distance from this location to the Pier 91 facility is less than five miles. Tide level measurement results are available in data sets having any one of the following measurement frequencies:

- one per six minutes;
- one per hour; or
- at times of high and low water.

In the Seattle area the tide is semidiurnal; two high tides and two low tides occur per tidal cycle (approximately 25 hours). Burlington will obtain a data set that corresponds to the tidal monitoring session, and that includes a measurement frequency of one per hour or greater. The data set will be obtained from the NOS Tidal Datum Section in Rockville, Maryland. Normally such data are not made available to the public until approximately 30 days following the last day of the month in which the data are collected. The data set will include information on the datum level, the time system (e.g., Pacific Standard Time), the measurement frequency, and the measurement units. Burlington will also request that the NOS provide specifications on the accuracy and precision of their tide measurement system. If such information is provided to Burlington, it will be included in the final written report (see Section 5).

3.2 Groundwater Levels

Water levels will be measured in all seven of the deep-aquifer monitoring wells regularly over each of the two tidal monitoring sessions. These include the existing wells CP-103B, CP-104B, CP-105B and CP-108B, and the proposed new wells CP-106B, CP-115B and CP-122B. Upon completion of the first tidal monitoring session and interpretation of the data, Burlington will evaluate the need for an additional deep-aquifer monitoring well (CP-107B). The final decision on whether or not to install an additional well will be made jointly by representatives of Burlington and the USEPA. If an additional deep-aquifer monitoring well is installed, the water level will be measured in all eight deep-aquifer monitoring wells during the second tidal monitoring session.

The duration of each tidal monitoring session will be 75 hours. This duration is approximately equal to that suggested by Serfes (1991) for determining the mean hydraulic gradient of a tidally-influenced groundwater system. The measurement frequency will be at least two per hour. Since the majority of the total variation in water levels is expected to be that associated with tidal forcing, and this forcing has a period of approximately 12.5 hours, a measurement frequency of two per hour should be adequate to characterize the tidal response of the groundwater system.

Water-level measurements will be made using an electronic data acquisition/storage system consisting of a data logger and submersible pressure transducers. One pressure transducer will be placed in each of the deep wells. In addition, water levels in the wells will be measured periodically using an electronic water-level indicator. Data collected using the electronic water-level indicator can be used as a check for the electronic data acquisition system, and can be used as a backup in case of equipment failure. Equipment to be placed inside monitoring wells will be decontaminated prior to use according to the procedures specified in the RFI Work Plan (Burlington, April 1992).

3.3 Barometric Pressure

Barometric pressure will be monitored during each tidal monitoring session using either a portable barometer or a barometric pressure transducer and an electronic data logger. The measurement frequency will be at least two per hour. The collection of barometric pressure information is necessary to differentiate groundwater response to tidal effects from groundwater response to barometric effects.

3.4 Hydraulic Conductivity

Although some hydraulic conductivity test data from previous investigations (Sweet-Edwards/EMCON; 1988, 1989) are available, the RFI Work Plan specifies the collection of additional hydraulic data. Methods proposed for the collection of these data include laboratory permeability testing of samples from the silty sand layer, and slug testing of the new monitoring wells. These activities will be completed before the tidal monitoring data are interpreted. In addition, as part of Burlington's response to USEPA's comments on the RFI Work Plan, Burlington has proposed a deep-aquifer pumping test. All of these activities are to be conducted as part of the RFI and are described in the RFI Work Plan. Therefore, although these activities are related to the tidal monitoring effort, they are not considered to be within the scope of this tidal monitoring program.

4 DATA ANALYSIS

Sections 4.1 through 4.3 outline analyses to be performed on the data collected from each tidal monitoring session, while Section 4.4 describes the analysis of seasonal effects.

4.1 Time-Varying Hydraulic Response

One objective of tidal monitoring is to understand the effects of tidal forcing on the deep aquifer groundwater system. Based on theory (Todd, 1980) and results of previous work (see Section 2), tidal forcing is expected to cause a periodic or quasi-periodic transient in the deep aquifer groundwater levels. Accordingly, efforts will be made to document and illustrate the transient nature of the deep aquifer's hydraulic response. The following subsections describe how this will be accomplished.

4.1.1 Groundwater Levels

To aid in recognizing spatial and temporal trends in the hydraulic response, a graph of measured groundwater-level versus time will be prepared for each of the deep-aquifer monitoring wells. Two sets of these graphs will be produced - one for each of the two tidal monitoring sessions.

In addition, thirteen contour maps of the instantaneous deep-aquifer potentiometric surface will be compiled for each tidal monitoring session. The maps will correspond to consecutive six-hour periods. These maps will be helpful for illustrating the temporal variation of the hydraulic gradient throughout the tidal monitoring session.

4.1.2 Hydraulic Gradients

In principle, the direction and specific discharge of flowing groundwater can be predicted if the hydraulic gradient and the hydraulic conductivity are known. As such, the hydraulic gradient is a useful indicator of the tendency for groundwater motion. The hydraulic gradient is a vector with three directional components. These include two horizontal components and a vertical component.

The horizontal components (x, y) of the hydraulic gradient in the deep aquifer will be estimated using the water-level measurements from the deep-aquifer monitoring wells (see Section 3.2). These calculations will be based on the assumption that the flow in the deep aquifer is approximately horizontal. Two approaches will be utilized for estimating the hydraulic gradients. These approaches are described below.

In the first approach, the estimates will be compiled for three triangular areas in the deep aquifer. Each of these areas is defined by the three deep-aquifer monitoring wells that form the vertices of the triangle. These areas are described in Table 1. The gradient estimates will be based on the assumption that the potentiometric surface within each triangular area approximates a plane. A computer can easily be programmed to automatically perform these simple calculations. One such estimate of the hydraulic gradient will be provided for each set of water-level measurements collected during the tidal monitoring session. For example, if water levels are measured twice per hour, then one horizontal gradient estimate will be compiled for each of the three triangular areas, for every half hour of tidal monitoring. To help infer temporal trends in the horizontal groundwater flow, graphs of hydraulic gradient magnitude and azimuth, versus time, will be prepared for each of the three triangular areas.

In the second approach, estimates of the hydraulic gradient will be compiled by graphical analysis of the 13 potentiometric surface contour maps described in Section 4.1.1. For each map, the following estimates will be compiled:

- the average gradient across the Burlington Pier 91 facility (leased property);

Table 1

AREAS FOR ESTIMATION OF HYDRAULIC GRADIENT

Triangular Area	General Location	Locations of Defining Vertices (Deep-Aquifer Monitoring Wells)
1	North side	CP-104B, CP-105B, CP-115B
2	West side	CP-103B, CP-104B, CP-106B
3	South side	CP-103B, CP-108B, CP-122B

- the direction and magnitude of the maximum hydraulic gradient; and

- the direction and magnitude of the minimum hydraulic gradient.

The areas of maximum, minimum, and average gradient will be selected by visual examination of the contour maps. This approach allows additional information, such as the shape of the potentiometric surface contours, to be incorporated in the estimates. However, this approach is more laborious and time-consuming because it is not amenable to automatic computation.

4.2 Time-Averaged Hydraulic Response

One of the objectives of this study is to infer the time-averaged or net groundwater flow in the deep aquifer beneath the site. This requires the estimation of time-averaged water levels or hydraulic gradients. The following subsections describe how time-averaged quantities will be estimated.

4.2.1 Groundwater Levels

Burlington will tabulate the time-averaged groundwater levels in all of the deep-aquifer monitoring wells for each tidal monitoring session. The time-averaged groundwater level in each well will be estimated by calculating the arithmetic average of the water-level measurements from that tidal monitoring session.

4.2.2 Hydraulic Gradients

The time-averaged horizontal components of the hydraulic gradient in the deep aquifer will be estimated and tabulated. The time-averaged gradient for each of the three triangular areas will be estimated by calculating the gradient of the corresponding time-averaged groundwater levels for each tidal monitoring session.

4.3 Tidal Response Parameters

The characteristics of the tidal response will be expressed using three parameters. These parameters, which include the amplitude, phase (time lag), and tidal efficiency, will be estimated and tabulated for each tidal monitoring session:

- amplitudes and phases of measured water-level fluctuations in all of the deep-aquifer monitoring wells;
- amplitude and phase of the tidal fluctuation in Elliott Bay; and
- tidal efficiency of the deep aquifer, at each of the deep-aquifer monitoring wells.

Tidal efficiency is defined as the ratio of the amplitude of groundwater-level fluctuations to the amplitude of tide level fluctuations (Todd, 1980). The amplitudes of these quantities can be determined various ways, including graphically, or by calculation of root-mean-square or standard deviation (see Erskine, 1991). The phases can also be determined either graphically or by a numerical procedure such as least-squares (Erskine, 1991). For each case, the method of calculation will be specified in the final report.

4.4 Seasonal Effects

Tidal monitoring and analysis will be conducted during two distinct periods, in order to infer seasonal variations in the tidal response of the groundwater system. The two tidal monitoring sessions will occur approximately at the times of high and low groundwater level at the site. Data from monthly water-level measurements indicate that these are likely to occur during the months of February and August, respectively. The results from the two tidal monitoring sessions will be compared, to infer seasonal variations in the groundwater system's tidal response.

5 REPORTING

After the second tidal monitoring session, when all of the pertinent data have been obtained and analyzed, Burlington will prepare a final written report. The report will contain all of the data collected during both tidal monitoring sessions, and the results of calculations pertaining to the quantities discussed in Section 4 (above). The report will be submitted to the USEPA within 45 days of Burlington's receipt of the required tide level data from the NOS.

REFERENCES

Burlington Environmental Inc. April 1992. RCRA Facility Investigation Work Plan, Burlington Environmental Inc. Pier 91 Facility, Seattle, Washington. Prepared for Burlington Environmental Inc.

------. October 1992. Tidal Monitoring Work Plan for RCRA Facility Investigation, Burlington Environmental Inc. Pier 91 Facility, Seattle, Washington. Prepared for Burlington Environmental Inc.

Converse GES. 1989. Preliminary Hydrogeologic Assessment Report, Terminal 91 Facility, Seattle, Washington. Prepared for Pacific Northern Oil.

------. 1990a. Phase I Remedial Investigation, Terminal 91 Facility, Seattle, Washington. Prepared for Pacific Northern Oil.

------. 1990b. Interim Product Extraction System Remedial Action Plan, Terminal 91 Facility, Seattle, Washington. Prepared for Pacific Northern Oil.

Erskine, A.D. 1991. The Effect of Tidal Fluctuation on a Coastal Aquifer in the UK. Ground Water. v. 29, no. 4, pp. 556-562.

Pacific Groundwater Group and Converse Consultants Northwest. 1990. Revised Hydraulic and Transport Model, Terminal 91 Short Fill, Seattle, Washington. Prepared for the Port of Seattle.

Serfes, M.E. 1991. Determining the Mean Hydraulic Gradient of Ground Water Affected by Tidal Fluctuations. Ground Water. v. 29, no. 4, pp. 549-555.

Sweet-Edwards/EMCON, Inc. 1988. Phase I Hydrogeological Investigation, Chemical Processors, Inc. Pier 91 Facility, Seattle, Washington. Prepared for Chemical Processors, Inc. Seattle, Washington.

------. 1989. Hydrogeologic Investigation, Pier 91 Facility, Chemical Processors, Inc. Prepared for Chemical Processors, Inc. Seattle, Washington.

Todd, D.K. 1980. Groundwater Hydrology. Second Edition. John Wiley & Sons, New York.

U.S. Environmental Protection Agency. July 9, 1992. Letter from Michael Gearheard, USEPA, to John Stiller, Burlington Environmental Inc.

------. January 25, 1993. Letter from David Croxton, USEPA, to John Stiller, Burlington Environmental Inc.

PUMPING TEST WORK PLAN
FOR RCRA FACILITY INVESTIGATION
BURLINGTON ENVIRONMENTAL INC.
PIER 91 FACILITY
SEATTLE, WASHINGTON

February 1993

Prepared for:

Burlington Environmental Inc.
Seattle, Washington

Project 624878

Prepared by:

BURLINGTON ENVIRONMENTAL INC.
Technical Services Division
2203 Airport Way South, Suite 400
Seattle, Washington 98134-2027
(206) 223-0336

TABLE OF CONTENTS

1 PUMPING TEST SUMMARY

This section summarizes the purpose, objectives, schedule, and scope for the proposed pumping test.

1.1 Background and Purpose

This work plan outlines the pumping test proposed for the Burlington Environmental Inc. (Burlington) Pier 91 facility, as part of the RCRA Facility Investigation (RFI) to be conducted at that facility. An RFI Work Plan (Burlington, April 1992) for the Pier 91 facility was conditionally approved by the U.S. Environmental Protection Agency (USEPA) in July 1992 (USEPA, 1992). One of the conditions that the USEPA imposed as a requirement for final approval of the RFI Work Plan was that Burlington submit plans for the proposed pumping test. To satisfy that requirement, and to provide a basis for conducting the pumping test, Burlington submitted a pumping test work plan to the USEPA in October 1992 (Burlington, October 1992). After discussions were held between representatives of Burlington and the USEPA in December 1992, the USEPA submitted written comments on the work plan to Burlington (USEPA, 1993). Those comments have been addressed in this version of the work plan. This work plan, if approved, will become an addendum to the existing RFI Work Plan.

1.2 Objectives

The objectives of this pumping test are as follows:

- to infer the degree of hydraulic connection between the upper and lower water-bearing zones through the silty sand layer;

- to assess the hydraulic properties of the deep aquifer; and
- to check the consistency of other available hydraulic information, such as slug test results and laboratory permeability measurements.

1.3 Scope

The testing described in this work plan will be conducted in two parts: a brief step-drawdown test, followed by a constant-discharge pumping test. A detailed description of the scope of this work is given in the following sections. In summary, the scope includes the following elements:

- data collection;
- data analysis; and
- reporting.

The data collection element involves the acquisition of various types of data at selected time intervals throughout the test. Pertinent data include barometric pressure, tide levels, and groundwater levels. The data analysis element primarily involves the interpretation of the pumping test data, and their integration with hydraulic and stratigraphic data collected during previous site investigations, and other ongoing RFI activities. The reporting element involves the description of test procedures and analysis methods, summary of data and analysis results, and discussion of the results and conclusions.

1.4 Schedule

The field activities of the pumping test will be conducted following the installation and development of monitoring wells CP-106B, CP-122A and CP-122B. This timing is necessary because these wells, in addition to existing monitoring well CP-106A, are to be used for pumping or water-level observations during the test.

There will be a minimum 24-hour waiting period between the completion of certain types of field activities (e.g., drilling, well installation and development, and slug testing), and the initiation of the pumping test. This waiting period is intended to minimize unknown disturbances of the groundwater levels in the area prior to the test. Such disturbances could complicate the interpretation of the pumping test data.

The RFI Work Plan (Burlington, April 1992) calls for laboratory permeability testing of samples from the silty sand layer. This schedule is intended to allow Burlington to interpret the pumping test data after the results of the proposed permeability testing are available.

The pumping test will be performed after the initial session of the proposed tidal monitoring has been completed. The response of groundwater levels to tidal forcing, if not accurately accounted for, may partially or fully mask the response to deep-aquifer pumping. This might render the test useless, or at least require reinterpretation following completion of the tidal monitoring study. Therefore, it is prudent to interpret the pumping test data following the evaluation of tidal effects on the deep aquifer.

2 TEST DESCRIPTION

2.1 General Procedures

2.1.1 Step-Drawdown Test

Prior to the constant-discharge pumping test, a step-drawdown test will be performed. The purpose of the step-drawdown test is to assist in the selection of an appropriate discharge rate and duration for the constant-discharge pumping test. The step-drawdown test will be conducted in two periods, a drawdown period followed by a recovery period. The water level in the pumping well (CP-122B) will be monitored throughout both periods.

During the drawdown period, groundwater will be pumped out of the deep-aquifer well CP-122B. The drawdown period will consist of at least three stages or steps. The pumping rate will be held constant throughout each step, at a value that exceeds the rate used in the previous step. Each step will be of sufficient duration for the water level in the pumping well to approximately stabilize.

The recovery period will begin at the end of the last step of the drawdown period. The pump will be shut off at the start of the recovery period, and will remain off throughout the period. The water level in the pumping well will be allowed to recover approximately to its ambient state at this time. To increase the likelihood that the water level fully recovers, the duration of the recovery period will be at least as great as that of the drawdown period.

2.1.2 Ambient Monitoring

Following completion of the step-drawdown test, and prior to the start of the constant-discharge pumping test, water levels in selected wells will be monitored regularly. The purpose of this monitoring period is to assess temporal trends in ambient water levels. The duration of this ambient monitoring period will be at least 24 hours. Precautions will be taken to avoid disturbing the groundwater system during this period. For instance, no pumping or hydraulic testing will be conducted at this time. The wells to be monitored include CP-106A, CP-106B, CP-122A, and CP-122B.

2.1.3 Constant-Discharge Test

The constant-discharge test will involve a drawdown period during which water is pumped at a constant rate out of the deep-aquifer monitoring well CP-122B, followed by a recovery period of approximately equal duration, in which no pumping occurs. Water levels in wells CP-106A, CP-106B, CP-122A, and CP-122B will be measured and recorded throughout both periods.

The duration of the drawdown period has not yet been precisely determined, but is expected to be approximately 48 hours. The actual duration will depend on the measured response of the water levels. Ideally, the duration of the drawdown period would be sufficient to effect an observable response in the shallow aquifer water levels. However, practical considerations limit the drawdown period duration to a maximum 72 hours. Such considerations include the on-site water storage capacity, water testing and disposal costs, and test operating costs. An additional consideration in the choice of the test duration is that late-time water-level data are required to obtain reliable estimates of deep-aquifer hydraulic properties and to identify hydrogeologic boundaries.

The pumping rate will be determined based on data collected during the step-drawdown test. The rate is anticipated to be approximately 5 gallons per minute, but is dependent on the efficiency of the pumping well, aquifer thickness, and aquifer transmissivity and storage coefficient.

2.2 Decontamination

All equipment to be lowered into monitoring wells will be decontaminated according to the procedures specified in the RFI Work Plan (Burlington, April 1992). Such equipment includes:

- submersible pump housing, power cable and suspension line;
- pump discharge hose and pump/hose fitting;
- oil/water interface detector (probe and cable);
- electronic water-level indicator (probe and cable); and
- pressure transducer housings and cables.

2.3 Disposal of Discharge Water

Water discharged from the pumping well will be conveyed, via pipes and/or hoses, to an on-site tank trailer or holding tank prior to disposal. The water will be managed as a wastestream, as per Burlington's standard operating procedures, prior to treatment and/or discharge at one of the Burlington treatment, storage, and disposal (TSD) facilities.

3 DATA COLLECTION

Subsections 3.1 through 3.4 outline efforts to collect data during field activities associated with the pumping tests. Section 3.5 describes relevant data to be obtained from other sources.

3.1 Groundwater Levels

Water levels in wells will be measured using submersible pressure transducers. One pressure transducer will be dedicated to each of the monitored wells. The measurements will be made and recorded at preprogrammed time intervals using an electronic data logger. For the ambient monitoring period, the water level in each well will be measured once every 10 minutes. For each step of the step-drawdown test, and for the drawdown period of the constant-discharge test, the time intervals for water-level measurement will correspond to the following schedule.

Log Cycle	Elapsed Time	Time Interval
1	0-5 seconds	0.5 second
2	5-20 seconds	1 second
3	20-120 seconds	5 seconds
4	2-10 minutes	0.5 minute
5	10-100 minutes	2 minutes
6	>100 minutes	10 minutes

In this table, "Elapsed Time" refers to the time elapsed since the beginning of the step or period. This schedule will also be followed during the recovery periods of both the step-drawdown and constant-discharge tests.

In addition, the water levels in the wells will be measured periodically and recorded using one or more electronic water-level indicator(s). Measurements made with the water-level indicator(s) can be used as a check for the electronic data acquisition system, and may be used for backup in case of equipment failure.

3.2 Barometric Pressure

Barometric pressure will be measured and recorded hourly during the recovery period of the step-drawdown test, and during both the drawdown and recovery periods of the constant-discharge pumping test, using either a portable barometer or a barometric pressure transducer with an electronic data logger.

3.3 Volumetric Discharge Rate

For the aquifer tests described here, it is important to keep the discharge rate of the pump constant throughout the entire step or drawdown period. Variable discharge rates are difficult to monitor, complicate data interpretation, and may even render test results useless.

The discharge rate of the pump will be estimated and recorded periodically throughout the drawdown period of each test. The pump system will be adjusted as necessary to keep the discharge rate constant in time and close to the target value. The discharge rate will be estimated by using a totalizing water meter and by measuring the amount of time that is required to fill a calibrated container, such as a plastic bucket, with the water stream that is discharged from the pumping well. The discharge will be measured where the outlet line from the pumping well enters the holding tank, so that the estimate is not biased by head loss differences.

3.4 Tide Level

The National Ocean Service (NOS) regularly measures tide levels at the Colman Docks area of Elliott Bay. The distance from this location to the Pier 91 facility is less than five miles. Tide measurement results are available in data sets having any one of the following descriptions:

- one tide level measurement per six minutes;
- one tide level measurement per hour; or
- times and levels of high and low water.

Burlington will obtain a data set that corresponds to a period extending from 24 hours prior to the ambient monitoring period, to the end of the recovery phase of the constant-discharge test. The data set will have a measurement frequency of one per hour, or greater. The data set will be obtained from the NOS Tidal Datum Section in Rockville, Maryland. Normally such data are not available to the public until approximately 30 days following the last day of the month in which the data are collected. The data set will contain information on the datum level, the time system (e.g., Pacific Standard Time), the measurement frequency, and the measurement units. Burlington will also request that the NOS provide specifications on the accuracy and precision of their tide measurement system. If such information is provided to Burlington, it will be included in the final written report.

3.5 Other Data

Interpretation of the pumping test data discussed above will be facilitated by examination of additional site data. Potentially useful data from sources other than the pumping test include information from previous investigations and from other RFI activities. Relevant information collected during previous investigations includes the following (Sweet-Edwards/EMCON, Inc.; 1988, 1989):

- stratigraphic information;
- results of slug tests conducted in monitoring wells; and
- groundwater system tidal response data.

Relevant information to be collected through planned RFI activities includes the following:

- stratigraphic information collected during drilling of new monitoring wells;
- results of slug tests conducted in new monitoring wells;
- results of laboratory permeability testing of samples from the silty sand layer at the locations of the new deep wells; and
- results of the tidal monitoring program.

All of the activities that generate these data are to be conducted as part of the RFI and the test procedures and methods are described in the RFI Work Plan (Burlington, April 1992).

4 DATA ANALYSIS

4.1 Step-Drawdown Test

For the step-drawdown test, the following plots will be created:

- drawdown in the pumping well versus time;
- pump discharge rate versus time; and
- drawdown in the pumping well versus pump discharge rate.

These plots will be examined in an attempt to infer the relationship between discharge rate and drawdown. An appropriate discharge rate that will produce the desired drawdown will then be selected for the constant-discharge test.

4.2 Constant-Discharge Test

4.2.1 Corrections for Barometric and Tidal Effects

An attempt will be made to differentiate the effect of pumping from other effects on groundwater levels in the deep aquifer. These other effects include the observed barometric pressure fluctuations, tide level fluctuations, and temporal trends in ambient groundwater levels. Calculations for this purpose will be based on the assumption that the aquifer's response to each of these effects is independent of the others. That is, the effects are assumed to be additive:

$$h_{meas,i}(t) = h_{ambi,i}(t) - s_i(t) + h_{baro,i}(t) - h_{tide,i}(t)$$

where

t	=	time
$h_{meas,i}(t)$	=	measured water level at monitoring point i and time t
$h_{ambi,i}(t)$	=	ambient water level at monitoring point i and time t
$s_i(t)$	=	drawdown at monitoring point i and time t due to pumping
$h_{baro,i}(t)$	=	barometric component of water-level fluctuation at monitoring point i and time t
$h_{tide,i}(t)$	=	tidal component of water-level fluctuation at monitoring point i and time t.

In the equation above, the ambient water level is that water level that would be measured if there were no barometric pressure fluctuations, no tide-level fluctuations, and no pumping. This approach is consistent with that presented by Kruseman and de Ridder (1992). Solving this equation for the drawdown gives the following:

$$s_i(t) = h_{ambi,i}(t) - h_{meas,i}(t) + h_{baro,i}(t) - h_{tide,i}(t)$$

This relationship will be used to estimate the drawdown at the monitoring points. Ambient water levels will be estimated using water-level data from the recovery period of the step-drawdown test.

Water-level fluctuations caused by barometric pressure changes are assumed to obey the following conditions:

- the aquifer behaves as a perfectly elastic body, so that it responds instantaneously to barometric pressure fluctuations;

- due to the elastic nature of the aquifer, water-level fluctuations associated with barometric pressure fluctuations are directly proportional to such fluctuations;

- the proportionality factor is a constant that depends on the hydromechanical properties of the deep groundwater system; and

- the proportionality factor may vary seasonally (e.g., due to seasonal variations in loading caused by seasonal water-level variations in the shallow aquifer), but does not vary over the duration of the pumping test.

In summary, for relatively small changes in the total applied stress on the aquifer, such as those caused by changes in barometric pressure, the aquifer response is expected to be approximately elastic. Therefore the barometric component of the observed water-level fluctuations will be estimated as follows:

$$h_{baro,i(t)} = E_{baro,i} \times H_{baro}(t)$$

where

$E_{baro,i}$ = estimated barometric efficiency of the aquifer, at monitoring point i

$H_{baro}(t)$ = measured atmospheric pressure fluctuation, at time t, expressed in terms of equivalent head of pure fresh water.

Freeze and Cherry (1979) define the barometric efficiency of an aquifer as the ratio of the magnitude of barometrically induced water-level fluctuations to the magnitude of the simultaneous barometric pressure fluctuations (expressed in terms of equivalent head of pure fresh water):

$$E_{baro,i} = |h_i(t)| / |H_{baro}(t)|$$

where

$|h_i(t)|$ = amplitude of barometrically-induced water-level fluctuation at monitoring point i and time t

$|H_{baro}(t)|$ = amplitude of barometric pressure fluctuation at time t.

The barometric efficiency of each of the monitoring points utilized in the pumping test will be estimated using the above formula and water-level data collected during the first of the two planned tidal monitoring sessions.

The tidal component of the observed water-level fluctuations will be estimated based on the following assumptions:

- the tidal component of the observed water-level fluctuations is directly proportional to fluctuations in the tide level of Elliott Bay, lagged by some time value;
- the proportionality factor is a constant that depends on the hydromechanical properties of the deep groundwater system;
- the time lag is a constant that depends on the hydromechanical properties of the deep groundwater system; and
- the proportionality factor and the time lag may vary seasonally, but do not vary over the duration of the pumping test.

Based on these assumptions, the tidal component of the observed water-level fluctuations will be estimated as follows:

$$h_{tide,i}(t) = 0.01 \text{ x } E_{tide,i} \text{ x } H_{tide}(t-t_i)$$

where

$E_{tide,i}$ = estimated tidal efficiency of the aquifer at monitoring point i

$H_{tide}(t)$ = measured tide-level fluctuation at time t, expressed in terms of equivalent head of pure fresh water

t_i = estimated tidal time lag at monitoring point i.

Definitions and procedures for estimating the tidal efficiency and time lag are presented in the Tidal Monitoring Work Plan (Burlington, 1993).

4.2.2 Analysis of Corrected Water-Level Data

Corrected water-level data from the pumping test will be analyzed using standard aquifer test analysis methods, if possible. These methods include the use of log-log plots, semi-log plots, and type-curve matching. Special software designed especially for this purpose (e.g., AQTESOLV™) is available and will be utilized unless the data appear to be inconsistent with the solution options, or other problems make its application unpractical or impossible. In that case, other methods may be used. Solution options that are likely to be applicable, and are available in the current version of the AQTESOLV™ software, are those based on the work of Hantush and Jacob (1955) and Hantush (1960).

For the purpose of evaluating the degree of hydraulic connection between the shallow and deep aquifers, the water-level response of the shallow-aquifer monitoring wells will be compared to that of the deep-aquifer wells. An attempt will be made to explain the observed differences and similarities using conventional porous medium flow theory.

5 REPORTING

After the constant-discharge pumping test is completed and all of the pertinent data have been collected, tabulated and analyzed, Burlington will prepare a written report on the test. The report will describe field procedures followed during both the step-drawdown and constant-discharge tests, list raw data collected during the tests, discuss other findings and observations, describe calculations used in the data interpretation, and present conclusions. The report will be completed within 45 days of completion of the constant-discharge test. If at that time the draft RFI report has not yet been submitted to the USEPA, the pumping test report will be included as part of the draft RFI report. Otherwise, the pumping test report will be submitted to the USEPA as an addendum to the draft RFI report.

REFERENCES

Burlington Environmental Inc. April 1992. RCRA Facility Investigation Work Plan, Burlington Environmental Inc. Pier 91 Facility, Seattle, Washington. Prepared for Burlington Environmental Inc.

-----. October 1992. Pumping Test Work Plan for RCRA Facility Investigation, Burlington Environmental Inc. Pier 91 Facility, Seattle, Washington. Prepared for Burlington Environmental Inc.

-----. February 1993. Tidal Monitoring Work Plan for RCRA Facility Investigation, Burlington Environmental Inc. Pier 91 Facility, Seattle, Washington. Prepared for Burlington Environmental Inc.

Freeze, R.A., and J.A. Cherry. 1979. Groundwater. Prentice-Hall, Inc. Englewood Cliffs, New Jersey, 604 pp.

Hantush, M.S. and C.E. Jacob. 1955. Non-steady Radial Flow in an Infinite Leaky Aquifer. Transactions of the American Geophysical Union. v. 36, pp.95-100.

Hantush, M.S. 1960. Modification of the Theory of Leaky Aquifers. Journal of Geophysical Research. v. 65, no. 11, pp. 3713-3725.

Kruseman, G.P. and N.A. de Ridder. 1990. Analysis and Evaluation of Pumping Test Data. Second Edition. International Institute for Land Reclamation and Improvement. Wageningen, The Netherlands, 377 pp.

Sweet-Edwards/EMCON, Inc. 1988. Phase I Hydrogeological Investigation, Chemical Processors, Inc. Pier 91 Facility, Seattle, Washington. Prepared for Chemical Processors, Inc. Seattle, Washington.

-----. 1989. Hydrogeologic Investigation, Pier 91 Facility, Chemical Processors, Inc. Prepared for Chemical Processors, Inc. Seattle, Washington.

U.S. Environmental Protection Agency. July 9, 1992. Letter from Michael Gearheard, USEPA, to John Stiller, Burlington Environmental Inc.

-----. February 4, 1993. Letter from David Croxton, USEPA, to John Stiller, Burlington Environmental Inc.